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Recirculating Airlift for Aeration of Shallow Water Bodies

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ABSTRACT

The article is devoted to solving the issue of ensuring the efficient operation of aeration equipment in the conditions of shallow water bodies with an average depth of only a few meters. The article offers a technical solution for reducing the size of airlift aerators and increasing their performance by creating a recirculation movement of water inside the unit. With the help of a laboratory model, it was established that the dynamics of oxygenation of water in the pool with the help of a recirculating airlift is subject to a logarithmic dependence on the size of the flow regulator. It was possible to increase the oxygen concentration in the pool by 2.6 times within three hours as part of the simulation. The rate of water oxygenation was much higher than for a conventional airlift of the same size. The offered cost-efficient aeration unit, which uses wind flow as an energy source, can be used for fish farms and other applications.

Keywords: airlift aerator, eutrophication, recirculation aerator, water oxygenation.

INTRODUCTION

Surface water bodies are widely used by people in various spheres of the national economy, namely, for drinking and technical water supply, recreation, fish farming, shipping, electricity production, stormwater and wastewater disposal with different degrees of treatment. In recent years, the shallowing of rivers has been observed, which is a natural process, and over time, bottom sediments are redistributed in the water body: some areas become silted up, others erode. Extraction of water for the purposes of agriculture, industry and domestic needs has led to severe shallowing and loss of many water bodies without the possibility of their self-recovery. In Ukraine, the situation has worsened dramatically due to military operations as a result of unstable operation of water supply and drainage systems, poor provision of water treatment facilities with reagents and spare parts, the use of low-quality phosphates-based detergents in everyday life, unauthorized discharges of oil refining products, solutions of chemical and organic substances, etc. All this contributes to the increase in the growth rates of algae and coastal plants, followed by the sedimentation of organic remains such as dead hydrobionts, other suspended substances and the reduction of the depth of water bodies and rivers.

Therefore, due to shallowing and water pollution, the threat of eutrophication has increased significantly, and there are no effective ways and means to prevent this process. Ensuring the standard quality of water resources has become a state-wide task for Ukraine. Ensuring the necessary level of oxygen in water bodies with a shallow depth has become a particularly urgent issue for Ukraine. A reliable way to solve this issue is to develop technical solutions that ensure the regulation of the parameters of the state of the water area within the limits stipulated by the standards and prevent their eutrophication.

REVIEW OF UP-TO-DATE PUBLICATIONS

In Ukraine, most water bodies do not exceed 7 meters in depth (Grebin et al., 2014), therefore the water layer warms up quickly and the main issue is to regulate temperature of the shallow water bodies. When the water temperature in the summer is above 25 °C, the solubility of oxygen in a water body decreases rapidly, and in winter, when a water body is covered with ice, air exchange stops, and therefore, oxygen deficiency develops (Kostenko et al., 2018; Golosov et al., 2012).

Such negative factors lead to eutrophication, the process of 'ageing' of water bodies, which is determined by an excess of biogenic elements and excessive production of organic matter as a result of natural and anthropogenic factors. Eutrophication should be considered as a part of a process known as the succession of water bodies, i.e. the change of one type of biocenosis to another in a negative direction, which, usually takes place over hundreds of years (Nowicka-Krawczyk et al., 2022; Sender et al., 2017). In recent years, under the influence of industrial and agricultural activity, the eutrophication of water bodies and, therefore, their succession, increased sharply. In the territory of Ukraine, the negative process is accelerating because of Russia's aggressive military actions.

Modern researchers identify the factors, mediating the spread of 'blooming' of water bodies, as follows:

- in summer, it is an excessive increase in the amount of biogenic substances (Kasza, 2017; Janicka et al., 2016) and the decomposition of plants and animals in the water body, low turbulence, an increase in temperature, and, as a result, a decrease in the content of oxygen dissolved in the water, a decrease in transparency. It is noted that this is also facilitated by the tendency to regulate river flows and the development of hydraulic engineering (Sherman et al., 2013);
- in winter, it is covering the water with an ice layer, restricting the gas exchange between air and water, which leads to a lack of oxygen in the latter.

As the researchers have established, one of the effective ways to combat eutrophication is to saturate the water body with oxygen (i.e. aeration). Oxygenation of the water body helps to slow down the process of eutrophication, reduce nitrogen compounds, which is one of the main nutrients in the emergence of the blooming of the water body (Dong et al., 2012).

A good example of aeration is the use of a geothermal shaft airlift, which made it possible to ensure a water temperature of 10 to 25 °C throughout the year, which is especially important both in summer and in winter (Chepak et al., 2019). Furthermore, year-round provision of comfortable conditions for such plants as phragmites, typha, eichhornia, yellow irises, and common knotgrass, made it possible to extract nutrients, nitrates, and heavy metals from the runoffeffectively, which further improved water quality.

Many authors have noted that in the process of aeration, the diameter of the air bubbles themselves plays an extremely significant role in the process of oxidation of the water body (Ekhlas et al., 2020; Abed et al., 2021). It was established that a decrease in the diameter of the bubbles leads to an increase in the oxygenation of the water body (Luty et al., 2020).

Experimental studies (Kostenko et al., 2022) proved the quite effective use of a two-stage aerator airlift. The oxygen concentration increased by 3.5 times when using it compared to a conventional single-stage aerator. However, such a design has a significant vertical size, which limits the ability to use two-stage airlifts in shallow water bodies effectively.

The use of aeration technical means requires energy. This prevents their wide implementation in the communities and farms. With the current shortage of energy resources and the tendency to their cost rising, as well as taking into account the negative impact on the environment of conventional methods of obtaining energy, there are good reasons to use alternative energy sources. Wind energy is considered promising and suitable for ensuring the operation of aeration units near the water areas (Bashutska et al., 2020). A design of the wind turbine is known (Boog et al., 2016), which ensures the operation of the blower, but the main drawback for saturating the water with air was the design itself, because it is not suitable for the water areas.

A brief review of the latest sources of information allows us to state that the main urgent issue for shallow water bodies is the provision of the necessary oxygen concentration and stabilization of the water temperature, both in summer and in winter.

THE PURPOSE AND OBJECTIVES OF THE STUDY

Thus, summarizing the known data, it can be stated that the main objective is to solve the issue of ensuring the efficient operation of aeration equipment in the conditions of shallow water bodies with an average depth of only a few meters.

The purpose of the study is to justify a pragmatic approach to the creation of compact technical means of regulating the concentration of water oxygen in the shallow water bodies. The subject of the study is the technologies of aeration of shallow water bodies. The object of the study is the main regularities of the oxygen regime of water bodies during the operation of compact aeration units. The study methods are theoretical justification and experimental laboratory research of the dynamics of water oxygenation using aeration technical means of the recirculating type were used in this study.

STUDY RESULTS

The rate of oxygen deficiency in the water of the waters has increased sharply since the mid-1950s, and the problem of eutrophication has become one of the most urgent problems of our time. Most clearly, this can be observed on the example of fish farming, because the oxygen concentration in water is standardized for this field of activity. In recent years, not only lakes and water bodies, but also water areas that are also used for fish farming, such as river spaces and the Sea of Azov, have been eutrophicated.

In fish farming, the minimum threshold values of oxygen concentration are taken into accountfor somespecies of fish. The content of dissolved gases can be expressed in terms of volume (mL/L) (Shekk, 2017) or weight (mg/L) (Table 1).

However, in artificial fish farming, there are no reasons to allow oxygen threshold values, because this is the critical value at which the fish is in a state of stress, which precedes fatigue.

Usually, the ‘blooming of a water body’ begins with an increase in the flow of biogens, primarily phosphorus and nitrogen. Saturation of the water body with biogens leads to an increase in the biomass of the initial links of the trophic chain: abundant development of bacteria, phytoplankton and zooplankton.

An increase in the number of suspended particles in the water layer leads to a decrease in its transparency, and, therefore, contributes to an increase in the temperature of the surface layers of water under the influence of sunlight. This leads to the formation of a so-called ‘water wedge’, which prevents mass transfer between the upper and lower layers of water and contributes to oxygen deficiency in the water body.

Oxygen deficiency appears in hypolimnion water bodies and fatigue zones are formed, which do not disappear, and lead to the death of fish, which in turn leads to economic losses of fisheries.

The zone of physiological comfort for most species of fish is from 100% to 70% (14–10 mgO_2/L) of normal oxygenation, with normal saturation not less of 4 mgO_2/L. If the content of dissolved O_2 decreases, the physiological activity of hydrobionts decreases, feed is used less rationally, and fish grow worse. The greatest oxygen deficiency is usually observed in the summer period of the year, when the water body temperature rises above 25 °C. The solubility of oxygen in

Table 1. Critical oxygen concentration in water for some commercial fishery species

Genus	Specie	Threshold values of oxygen concentration	
		mL/L	mg/L
Cyprinidae	Carp	0.74–1.00	1.05–1.43
	Crucian	0.06–0.09	0.09–0.13
	Roach	0.11–0.30	0.15–0.43
	Tench	0.09–0.30	0.13–0.43
Acipenseridae	Sturgeon	0.99–1.30	1.41–1.85
	Starred sturgeon	1.30–1.70	1.85–2.43
	Sterlet	1.50–2.40	2.14–3.43
Salmonidae	Trout	1.30–1.80	1.85–2.57
	Salmon	0.79–1.30	1.13–1.86
Percidae	Perch	0.50–1.00	0.72–1.43
	Zander	0.39–0.60	0.56–0.86

water at this temperature is low, and the conditions for the development of pathogenic microorganisms, such as blue-green algae, are the best.

In winter, the oxygen concentration in the ponds is low because of a layer of ice forming on the surface, which prevents gas exchange, and the reduced illumination of the layer prevents photosynthesis.

Therefore, the primary task is to ensure the necessary concentration of oxygen for the high-quality existence and development of fish, as well as temperature regulation, in water bodies of artificial fish farming. The use of units of the airlift type is justified. Oxygenation occurs in the column of the airlift as the air bubbles move through the water layer (Kostenko et al., 2022).

The airlift units are designed to improve the condition of water in a state of eutrophication, i.e., it has a reduced oxygen concentration and there are conditions for the development of anaerobic hydrobionts. Eutrophication can develop in two cases: when the water body is covered with ice and the gas exchange between water and air is stopped, or when the water is heated to a high temperature, when the ability of water oxygen to dissolve is reduced. To prevent the formation of a low-oxygen state of water, it is necessary to ensure the water temperature in the warm season in the range of 0 °C to 25 °C, and above 0 °C in the cold season. In open water bodies, a low oxygen concentration is observed when the water is heated above 25 °C in summer, while dissolved nitrogen in various forms is in a state close to saturated. A difficult problem is the dissolution of oxygen in the water body at normal atmospheric pressure and water and air temperatures above 25 °C, when the use of aeration becomes less effective.

The solution to this problem can be the use of water conditioning units by maintaining the temperature in the range of 5 °C to 15 °C by means of a geothermal heat exchanger (Kostenko et al., 2021). An airlift is the initiator of flow rate in the unit with the air compressor, driving a wind generator as a recommended source of power. Water from a water body, which has a reduced content of dissolved oxygen, serves as the working fluid in the airlift. It is proposed to fight eutrophication in two stages: first, to cool water down to a temperature of no more than 25 °C, at which there are no conditions for the intensive development of anaerobic hydrobionts, and second, to saturate water with oxygen. Saturation of water with gas at an air temperature of more than 25 °C is preferably to be carried out in the column of an airlift with an increased hydrostatic pressure, which increase the solubility of gases.

Water with a low oxygen concentration enters an aerator airlift of a conventional design (Chepak et al., 2019; Luty et al., 2020), and the water is oxygenated when it comes into contact with air. Contact of water with air occurs when the flow of air bubbles created by the spray nozzle passes through the airlift chamber filled with water. The process of passage of oxygen to water takes some time. Due to the limited dimensions of the aerator airlift, the time of contact ofair bubbles with the fluid is relatively short; therefore, the oxygenation of the water is incomplete. Especially ineffective prevention of eutorification can take place in water bodies that have a small depth and, therefore, the geometric dimensions of the aerator airlift cannot be large enough to oxygenate the water due to the short time of its contact with air bubbles.

In the well-known two-stage airlift (Kostenko et al., 2022), the lower stage has an increased diameter, where the velocity of bubbles is relatively small, and the time of their contact with water is increased. The first stage of the airlift, located at a greater depth, has maximum hydrostatic pressure and solubility of gases in water. The upper stage has a smaller diameter, which contributes to the increase in the velocity of upward movement of the water flow with bubbles. As it rises to the top, the hydrostatic pressure decreases, which leads to degassing of the water, but due to the increased velocity, this process has a small effect on the state of the water, and it enters the water body oxygenated. The effective operation of a two-stage aerator requires a significant depth; therefore, it is unsuitable for shallow water bodies.

It was proposed to improve the well-known aerator airlift for intensifying water oxygenation and overcoming the threat of its eutrophication by increasing the time of contact of air with water. The improvement is that the recirculating aerator, which contains the airlift pipe section, the spray nozzle, the geothermal heat exchanger with filter and the compressed air line, additionally contains a closed outer housing with a flow regulator installed in its upper part and connected to the geothermal heat exchanger pipe with filter in its lower part. Moreover, the airlift pipe section is installed inside the outer housing, and the air duct is equipped with a valve (Figure 1).

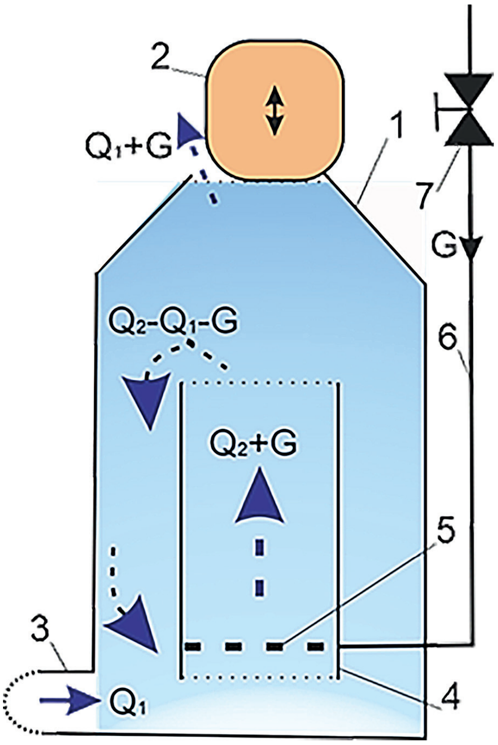


Figure 1. Recirculating aerator: 1 – outer housing; 2 – flow regulator; 3 – pipe of the geothermal heat exchanger with a filter; 4 – airlift housing; 5 – air spray nozzle; 6 – air duct; 7 – valve; G, Q – designations of air and fluid flows, respectively

The recirculating aerator is assembled as follows. The outer housing (1) of the unit has an opening in the upper part, where the flow regulator (2) is located, which is able to cover the passage section of the orifice, regulating the flow of the air-water mixture from the outer housing (1) to the water body. The geothermal heat exchanger (3) pipe, equipped with a mesh filter, is attached to the lower part of the housing (1). The housing of the airlift (4) is inside the outer housing (1), with the air spray nozzle (5) located in its lower part. The air is supplied to the spray nozzle (5) using the air duct (6) and regulated by the valve (7).

As the recirculating aerator operates, a mixture of air and water flows from the outer housing (1) to the water body through the void that remains between the walls of the housing (1) and the flow regulator (2), where the flow rate of fluid is Q_1, the flow rate of air is G. Water, which has a low oxygen concentration and a temperature similar to that of the lower layers of the water body, flows into the outer housing (1) from the heat exchanger (3) with a flow rate Q_1. Compressed air is supplied to the airlift (4) from the spray nozzle (5) from the air duct (6) with the flow rate G. The valve (7) regulates the supply of compressed air to the spray nozzle (5) from the air duct (6). Inside the airlift (4), a mixture of air bubbles and water is formed, which has a lower density than the water environment surrounding the airlift. The flow rate of the mixture in the airlift is $G + Q_2$, where Q_2 is the flow rate of the fluid part, which depends on the air supply G. Moreover, by regulating the supply of compressed air to the spray nozzle (5) with the valve (7), the fluid supply by the airlift Q_2 greater than Q_1 is set. As the water is mixed with air, oxygen diffuses from air to water; the efficiency of mass transfer depends on the duration of contact of air bubbles with water and the partial pressure of oxygen in the bubble.

A mixture of cooled and oxygenated water and air flows from the housing of the airlift (4) to the upper part of the void of the outer housing (1). Since the cross-sectional size of the outer housing (1) is larger than the airlift (4), when exiting the latter, the flow rate slows down and air bubbles overtake the movement of denser water. In the upper part of the outer housing (1), the air-saturated mixture enters the flow regulator (2). By changing the position of the regulator (2), the passage of the flow is regulated by the flow rate $G + Q_1$. Excess water with the flow rate $Q_2 - Q_1$ remains in the void of the outer housing (1) and returns to the inlet of the housing of the airlift (4), where it is mixed with water coming from the heat exchanger (3) with the flow rate Q_1. The cycle of saturation of the flow of water with oxygen inside the airlift (4) continues, however a mixture of water with a higher oxygen concentration is added to it. Dynamic equilibrium of such a process depends on the recirculation index $K_p = Q_2/Q_1$, which determines how much the flow of fluid moving in the airlift exceeds the aerator performance. In a certain period, the airlift (4) supplies $Q_2 = Q_1(1+K_p)$ of fluid, with a Q_1K_p portion of already oxygenated water in the flow; therefore, the oxygen concentration at the exit from the airlift (4) gradually increases and approaches a value that is stable under the given conditions, and which is significantly higher than the value inherent in the operation of the unit in the absence of recirculation, i.e, when $Q_1 = Q_2$.

Thus, due to the recirculation of a portion of the fluid flow, a technical result is achieved, i.e. an increase in the oxygen concentration in the process of aeration of water due to an increase in the time of its contact with air bubbles. Repeated return of a portion of the water flow to the airlift for oxygenation allows reducing the geometric dimensions of the unit without reducing the effective prevention of eutrophication of the water body. The use of a recirculating aerator makes it possible to create an area of oxygenated water in a shallow water body without eutrophication conditions.

With the use of a recirculating aerator, it becomes possible to build units for the prevention of water eutrophication in shallow water bodies with minimal operational losses (Figure 2). The technology of water oxygenation using the proposed unit is as follows. The recirculating aerator (see Figure 1) is arranged at the bottom of the water body; it is a good practice to arrange it near the places where the fish are fed. A mast with a wind power generator is installed on the surface. An air compressor acts as an electrical load, supplying compressed air via an air duct to a spray nozzle installed in the airlift. The rate of water oxygenation is regulated by changing the air flow; it is also possible to control the value of the recirculation coefficient by increasing or decreasing the size of the orifice in the flow regulator.

Two features were taken into account for the unit operation. Due to the unevenness of the wind flow, e.g. in a calm, the power of the wind generator may become insufficient to ensure the operation of the compressor. In this case, the compressor is connected to the conventional power grid. This allows for continued aeration in adverse weather conditions.

There is another situation when there is no need for water aeration in the water body. This happens when the temperature of water and air is naturally provided in the range of 0 to +25 °C. The duration of such meteorological conditions in Ukraine is quite long. In this case, excess electrical energy is supplied to the power grid according to a 'green' tariff. It is possible that such a power supply layout not only reduces costs for the construction and operation of the aerator, but also provides the owner with a profit.

Experimental verification of the effectiveness of water oxygenation was carried out by physical modelling of the airlift of the improved design.

Laboratory set-up (Figure 3) consisted of compressor (1), air duct (2) which passes into the air spray nozzle (3), cylindrical airlift housing with a diameter $Ø_1$ = 20 mm (4), which is connected to the outer housing of the aerator with a diameter $Ø_2$ = 40 mm (5), with the flow regulator (6). All elements of the recirculating aerator (positions 2–5) are made of transparent material and are immersed in a glass container, the pool (7) filled with water.

The principle of operation of the laboratory model: with the help of the compressor (1), air enters through the spray nozzle (3) through the air duct (2), forming swarms of air bubbles of small diameter, which are further supplied into the housing of the airlift (4). Water and air mix intensively inside the airlift; next, a portion of the mixture is supplied through the flow regulator (6) to the pool, and its other portion passes through the outer housing (5) and enters the airlift housing again. In this way, the time of water oxygenation

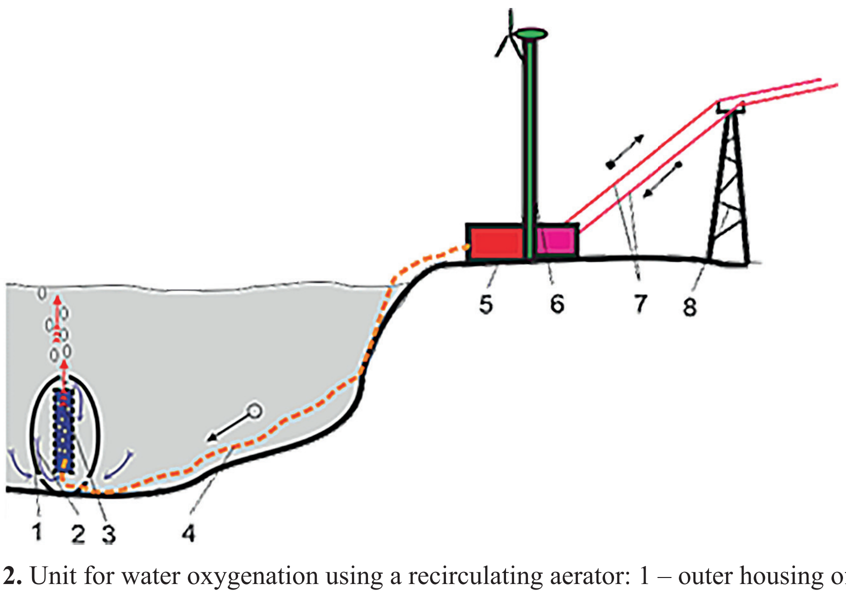


Figure 2. Unit for water oxygenation using a recirculating aerator: 1 – outer housing of the aerator, 2 – flow of recirculating water, 3 – airlift column, 4 – duct, 5 – compressor, 6 – mast with wind generator, 7 – electric power grid, 8 – power grid mast

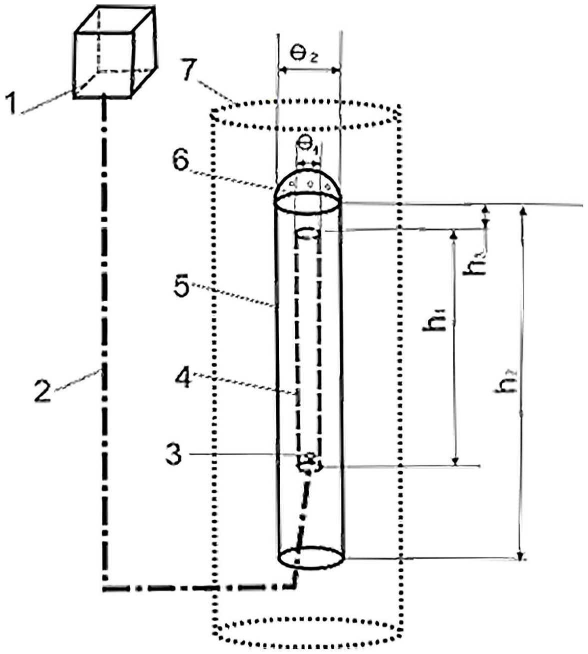


Figure 3. Layout of a laboratory set-up of the recirculating aerator: 1 – compressor, 2 – air duct, 3 – air spray nozzle, 4 – airlift housing (diameter Ø1, length h_1), 5 – outer housing of the recirculating aerator (diameter Ø2, length h_2), 6 – flow regulator, 7 – transparent container filled with water

increases, which creates conditions for increasing its concentration in the pool (7). In the recirculating aerator, the density of the water-air mixture is much lower than the density of water, thus gravitational forces push it upward, but a portion is supplied to the lower part of the airlift housing with the help of excess flow energy. Multiple mixing of water with air bubbles and additional diffusion of oxygen is provided.

The laboratory set-up of the recirculating aerator was connected to the 0.15 kW Bezan PANDA compressor, which provided four fixed modes of air supply through the spray nozzle, with a maximum capacity of up to 23 L/min.

The dimensions of the recirculating unit were unchanged, the airlift housing had a diameter of $Ø_1$ = 20 mm and a length of h_1 = 200 mm, the outer housing of the aerator had a diameter of $Ø_2$ = 40 mm and a length of h_2 = 300 mm, the distance between the flow regulator and the aerator housing was h_3 = 20 mm.

If we compare the dimensions with a similar model of a two-stage airlift-aerator (Chepak et al., 2019; Kostenko et al., 2022), this design has half the vertical size.

The change in oxygenation concentration over time was measured using a Xiaomi Redmi 9Pro electronic stopwatch.To compare the performance of the proposed design with a conventional aerator, a corresponding experimental comparison of the dynamics of water oxygenation was carried out.

The oxygenation level of water in the experimental set-up was determined by the reagent method. The experiment was carried out in the second mode of compressor supply; the air consumption in this case was 193.27 $m^3/s \cdot 10^{-6}$. Boiled water with a minimum oxygen concentration was poured into the pool of the experimental set-up with a volume of three litres; the initial concentration was 3 mg/L. Water was sampled for oxygen concentration analysis every five minutes.

When conducting an experiment for the water body aeration, six options of the sizes and shapes of the flow regulator were used (Table 2).

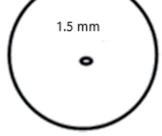
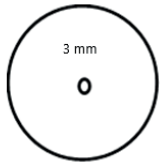
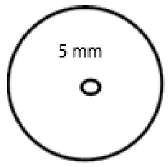
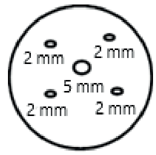
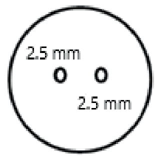
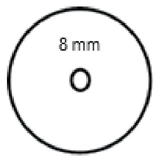
Four options of the simple circular regulator with diameters in mm were considered: 1.5; 3; 5; 8. In two more options, several orifices were tested; in one option, there were two orifices of 2.5 mm, in the second option, there was one central orifice of 5 mm, and four peripheral orifices of 2 mm. As a result of modelling, the following general picture of water oxygenation was established.

For the first 30 minutes of operation of the unit, there was an intense water oxygenation, and then the process slowed down (Figure 4). The maximum achieved oxygen level was 8 mg/L, when the unit was operating for more than 100 minutes; this is due to the fact that at a given temperature, pressure and volume of the closed system of the experimental set-up, water oxygenation was maximum possible.

Therefore, during long-term operation of the unit for aeration of limited volume of water, water oxygenation is ensured, the dynamics of the process is described by a logarithmic equation as follows $C = a * ln(t) + b$. This dependence was valid for all operation modes of the unit with different sizes and shapes of the orifices of the flow regulator.According to the results of statistical processing, the correlation ratio R^2 ranged from 0.8013 to 0.909 for different series of tests.

A comparison of the performance of the recirculating option and conventional option (only an airlift without an outer recirculating housing) showed that water oxygenation during the operation of a conventional airlift was only by 5 – 7% more efficient than a recirculating one with a plane of 1.7 mm^2 (see Fig. 3, curve 1). In all other options, recirculating airlift provided better performance.

Table 2. Geometrical parameters of the flow regulator of the recirculating aerator

Flow regulator option	Quantity * diameter of orifices, pieces * mm.	Total area of the regulator orifice, mm^2	Shape of the regulator and the diameters of the orifices
1	1 * 1.5	1.77	
2	1 * 3	7.07	
3	1 * 5	19.66	
4	1 * 5 + 2 * 2.5	32.22	
5	2 * 2.5	9.82	
6	1 * 8	50.24	

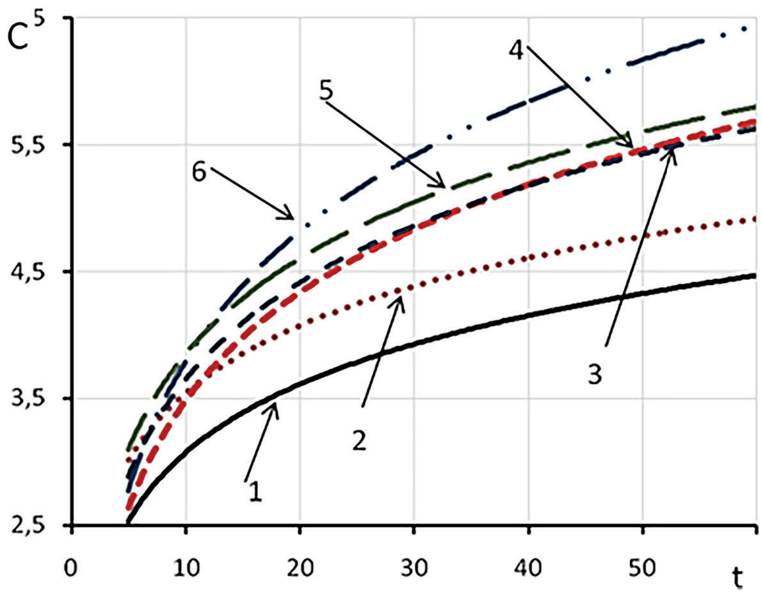


Figure 4. Dynamics of oxygenation (C, mg/L) of water with the area of the regulator orifice, mm^2: 1 – 1.77; 2 – 7.07; 3 – 19.66; 4 – 32.22; 5 – 9.82; 6 – 50.24

The results of measuring the addition of oxygen to water showed that when using regulators of a simple shape in the form of one round orifice, the rate of oxygenation is proportional to its plane (Figure 5). A comparison of the results shows that at the plane of the orifice S = 50.24 mm^2,the oxygenation rates were the highest; during two hours of the unit operation, the oxygen concentration in the pool increased more than 2.6 times. Intensive growth of oxygen concentration was observed when the plane of the orifice increased from one to 10–15 mm^2; further, growth is maintained, but the rate slows down.

The use of orifices of a complex shape, such as two or five orifices of different sizes and locations (see Table 2) did not give unambiguous results. The option of the flow regulator that had a total cross-sectional area of 32.22 mm^2 and consisted of five orifices (one with a diameter of 5 mm and four with a diameter of 2 mm) showed the results close to the option with one orifice with a plane of 5 mm 19.66 mm^2 (see Figure 4, curves 3 and 4). The option of the regulator with two orifices with a diameter of 2.5 mm, which gives a total area of 9.8 mm^2 demonstrated better results (see Figure 4, curve 5) than with one 5 mm orifice with a plane of 19.66 mm^2 (see Figure 4, curve 3).

DISCUSSION

The results of the conducted simulation confirmed the hypothesis regarding the effectiveness of using compact recirculating-type aerators to oxygenate water in shallow water bodies. By recirculating the gas-air mixture in the aerator housing, a longer contact of bubbles with water was ensured, and, therefore, the transfer of oxygen from air to water. The intensity of the aeration process is varied using the flow regulator.

The obtained qualitative indicators of the dynamics of water aeration with the help of compact recirculating-type means testify to their superiority over single-stage designs of the same vertical size. This type of aerator will be appropriate to use in low-water water bodies, due to its good performance and compact size.

The relatively long time of water oxygenation in the model pool, which was more than 100 minutes, can be explained by the compact size of the unit, which did not exceed 330 mm.This determines that the hydrostatic pressure in the void of the airlift was small, thus the speed of the oxygen diffusion process from the air bubbles to the water was small. Furthermore, the model geometric dimensions of the airlift (200 mm) and the aerator housing (300 mm) determined the limited period of bubbles in the model, and, therefore, the short contact time of air bubbles with the surrounding water. There is every reason to believe that in full-scale prototypes of the recirculating aerator, the rate of oxygen absorption by water will be much higher due to the much higher hydrostatic pressure of water and gas at a depth of several meters. The duration of the interaction between air and water will increase due to the larger linear dimensions of the actual aerator.

A comparison of different passage sizes of a simple type of flow regulators tested showed that the rate of water oxygenation increases with the increase in the size of the orifices. The regulator with a diameter of 8 mm and a cross-sectional

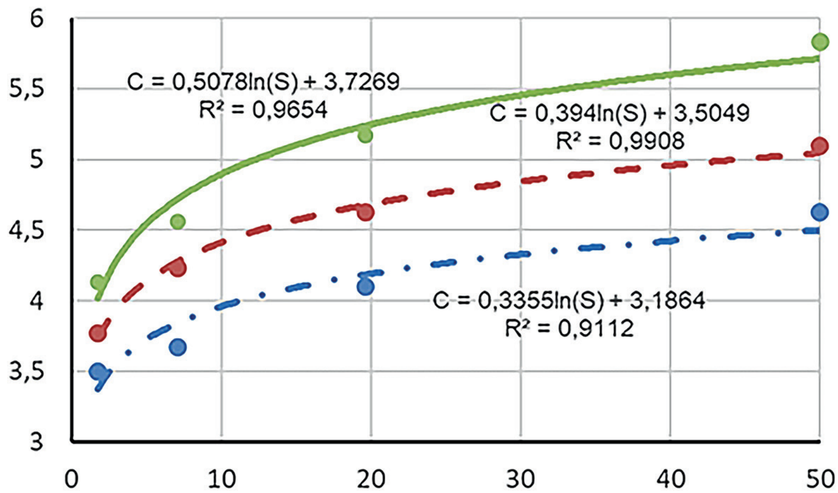


Figure 5. Dependence of the degree of water oxygenation (C, mg/L) on the plane of the orifice of the circular regulator (S, mm^2) during aeration for different times, min: 50 – solid, 30 – dashed, 20 – dash-dotted

area of 50.24 mm^2, which increased the oxygen concentration in the pool from 3.5 to 5.8 mg/L in 50 minutes of aeration, was the most efficient one. A regulator 2.7 times smaller, with a diameter of 3 mm and a cross-sectional area of 7.07 mm^2, provided an increase in oxygen to 4.6 mg/L under the same conditions. If the maximum level of water oxygenation under these conditions is 8 mg/L, and the input level is 3 ml/L with 0% is taken as 100%, then the indicators of oxygen increase reached 44 and 32%, respectively.

An attempt to use flow regulators of a complex shape did not give an unambiguous result. This can be explained by the fact that a two-phase medium (water + air) flows to the exit from the aerator housing, where the ratio between fluid and gas changes when moving through the orifice. An air-saturated flow with lower hydrodynamic resistance comes out through the orifice. Slowing down the flow in the housing of the recirculating aerator after exiting the housing of the airlift results in the phenomenon when air bubbles overtakes water. This leads to an increase in the size of the bubbles due to their merging and a decrease in the efficiency of gas exchange.

Unfortunately, due to the forced evacuation of the university, where the research was conducted, it was not possible to establish the rational parameters of the flow regulator and indicators of the recirculation coefficient for this model. This research is planned for the near future.

CONCLUSION

The vast majority of water bodies in Ukraine have a limited depth, which does not exceed 5 to 7 meters. Processes of succession and anthropogenic water pollution caused the decrease in water quality in most water bodies. Prevention of the process of eutrophication in shallow water bodies has become an important ecological and economic problem of water resources policy in Ukraine.

The effective use of conventional types of airlift-type aerators in shallow water areas is impractical due to their significant vertical dimensions. The authors put forward a hypothesis and proposed a technical solution for reducing the size of airlift aerators and increasing their performance by creating a recirculation movement of water inside the unit. Experimentally, with the help of a laboratory model, it was established that the dynamics of oxygenation of water in the pool with the help of a recirculating airlift is subject to a logarithmic dependence on the size of the flow regulator. It was possible to increase the oxygen concentration in the pool by 2.6 times within three hours in the simulation conditions. The rate of water oxygenation was much higher than for a conventional airlift of the same size.

For fish farms and other applications, an economical aeration unit is proposed, where wind flow serves as an energy source. With combined energy supply and the use of a 'green' tariff, this allows for reducing operating costs, and in some cases, returning the capital costs and make a profit.

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